Results from the Antarctic Muon and Neutrino Detector Array (AMANDA)

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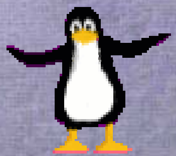
***For the most excellent marriage of particle physics and astronomy*:**

- <u>**Something old**</u>
    - **Recap of recent results**
- <u>**Something new**</u>
    - **New analyses of older data**
    - **New analyses of newer data**
- <u>**Something borrowed**</u>
    - **Extreme Cold Weather Clothing**
- <u>**Something blue**</u>
    - **Lips, fingertips, noses,…**



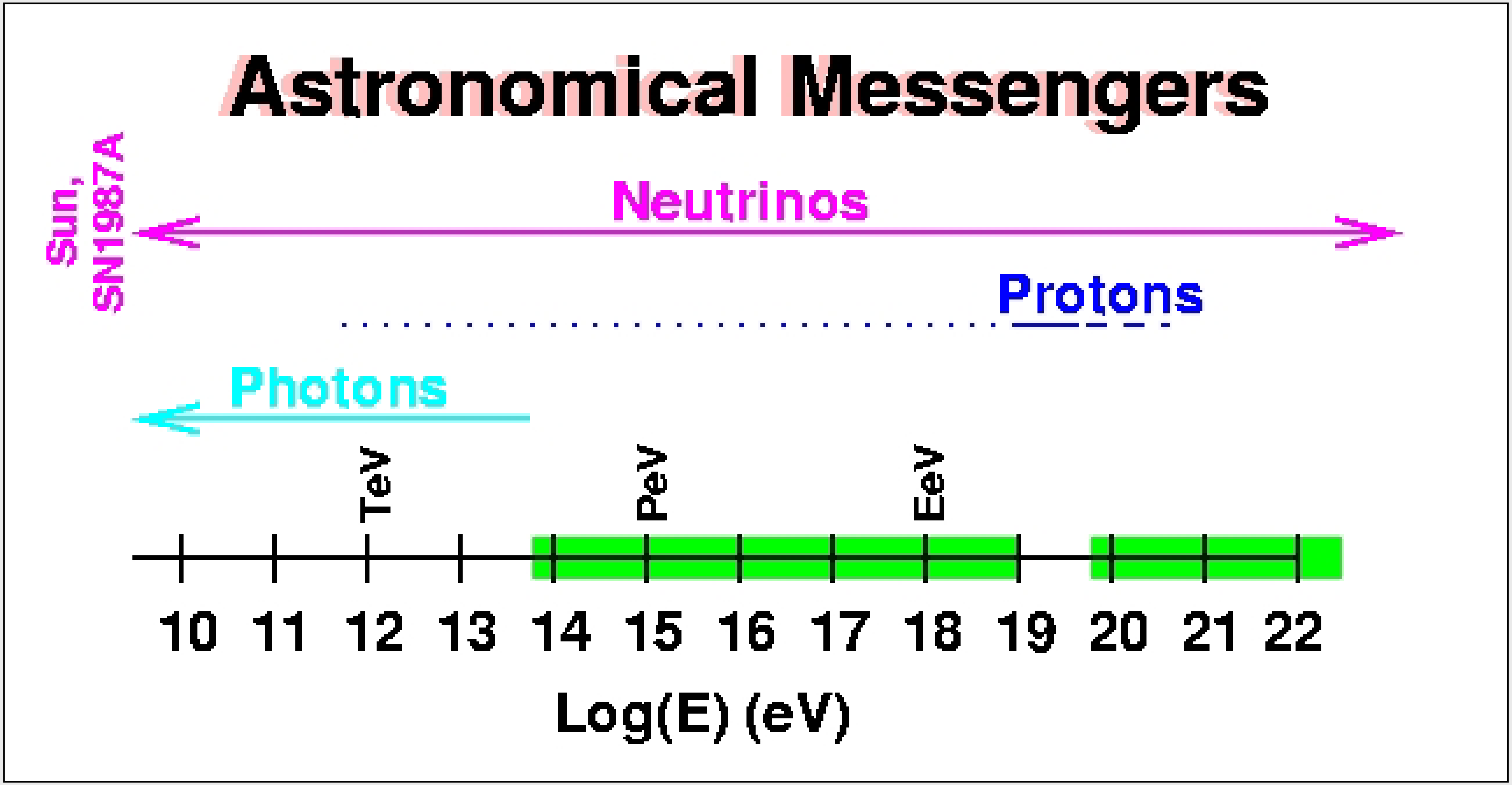
The South Pole

The AMANDA Collaboration

1 South American, 9 European and 7 US institutions, about 110 current members:

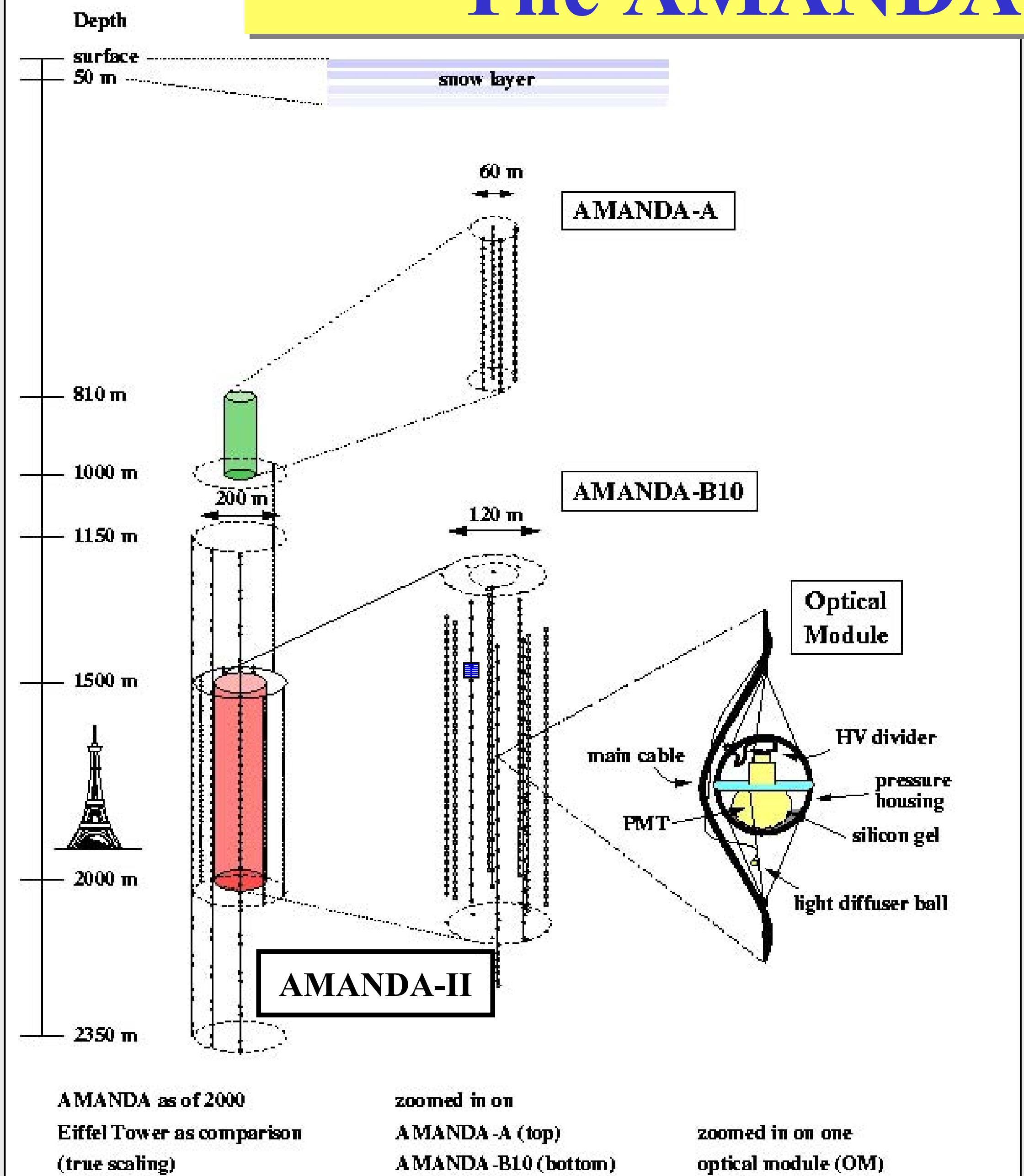
1. Bartol Research Institute, University of Delaware, Newark, USA
2. BUGH Wuppertal, Germany
3. Universite Libre de Bruxelles, Brussels, Belgium
4. DESY-Zeuthen, Zeuthen, Germany
5. Dept. of Technology, Kalmar University, Kalmar, Sweden
6. Lawrence Berkeley National Laboratory, Berkeley, USA
7. Dept. of Physics, UC Berkeley, USA
8. Institute of Physics, University of Mainz, Mainz, Germany
9. University of Mons-Hainaut, Mons, Belgium
10. University of California, Irvine, CA
11. Dept. of Physics, Pennsylvania State University, University Park, USA
12. Dept. of Physics, Simon Bolivar University, Caracas, Venezuela
13. Physics Department, University of Wisconsin, River Falls, USA
14. Physics Department, University of Wisconsin, Madison, USA
15. Division of High Energy Physics, Uppsala University, Uppsala, Sweden
16. Fysikum, Stockholm University, Stockholm, Sweden
17. Vrije Universiteit Brussel, Brussel, Belgium

Discovery Potential!



The Site:
5 cm of Powder, 2 km of Base,
Never Rains, and Lots of Non-stop Sunshine

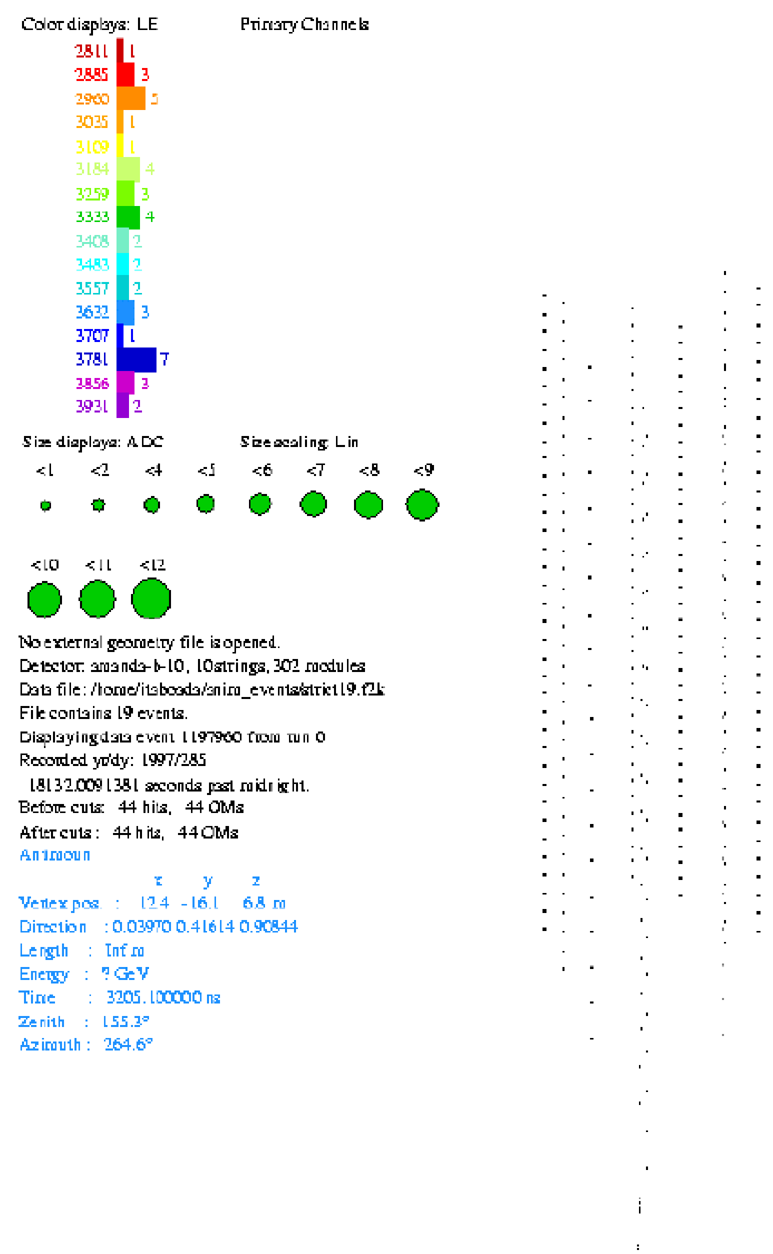
The AMANDA Detector



- Hot-water-drill 2km-deep holes & insert strings of PMTs in pressure vessels.
  - AMANDA-B10: 302 PMTs, completed in 1997
    - Old & new A-B10 results presented
  - AMANDA-II: 677 PMTs, completed in 2000
    - Prelimin. results presented
- AMANDA challenges:
  - Natural medium!
    - Blame Mother Nature
  - Remote location!
    - Blame Scott & Amundsen who made it look too hard to get there
  - Unfettered bkgd. source!
    - We'd all like to know exactly who to blame…
  - Prototype detector!
    - Can you blame us for trying to improve things?

AMANDA Event Signatures: Muons

CC muon neutrino interactions → Muon tracks



$$\nu_\mu + N \rightarrow \mu + X$$

AMANDA Event Signatures: “Cascades”

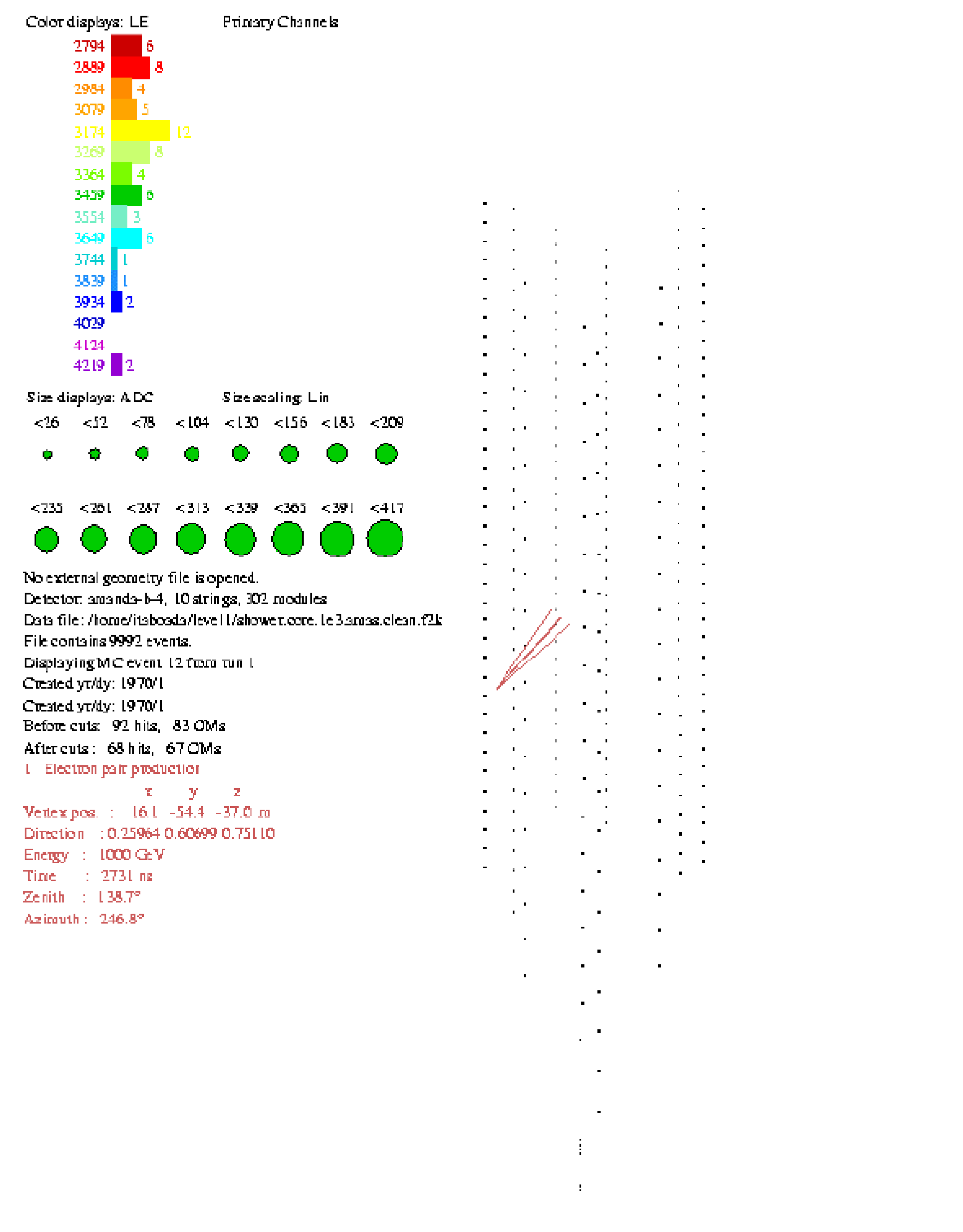
- **CC electron and tau neutrino interactions:**

  $\nu_{(e,\tau)} + N \rightarrow (e,\tau) + X$

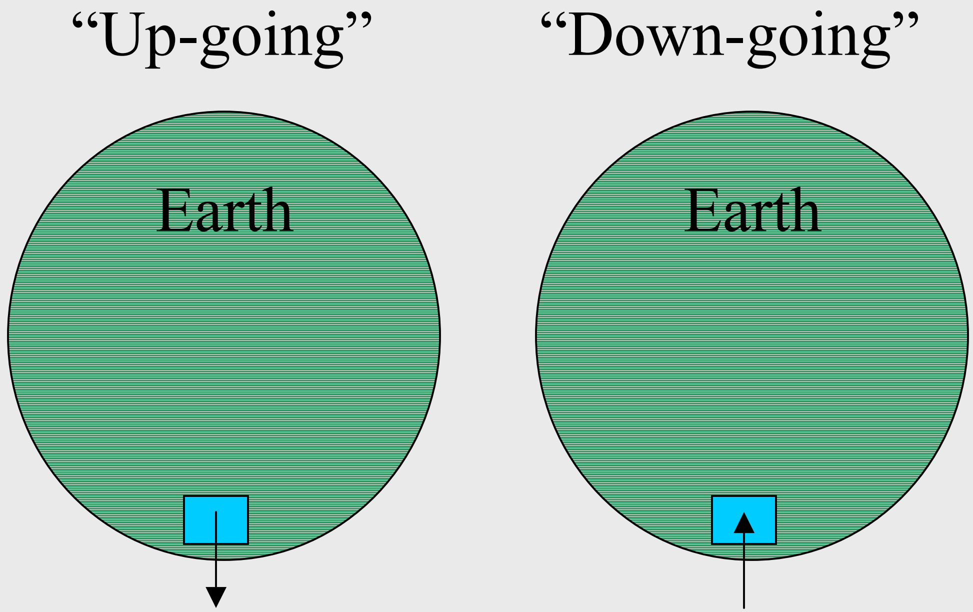
- **NC neutrino interactions:**

  $\nu_x + N \rightarrow \nu_x + X$

Cascades

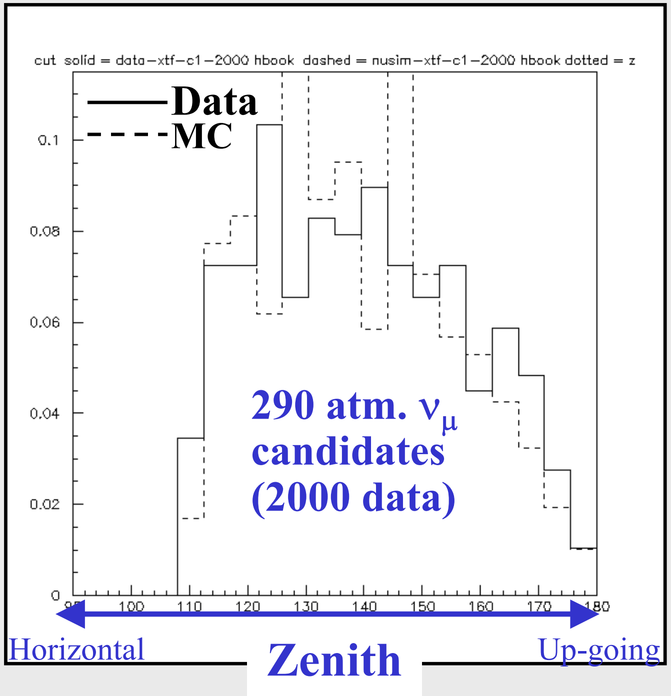


Important Definition for Northern Hemisphere Dwellers

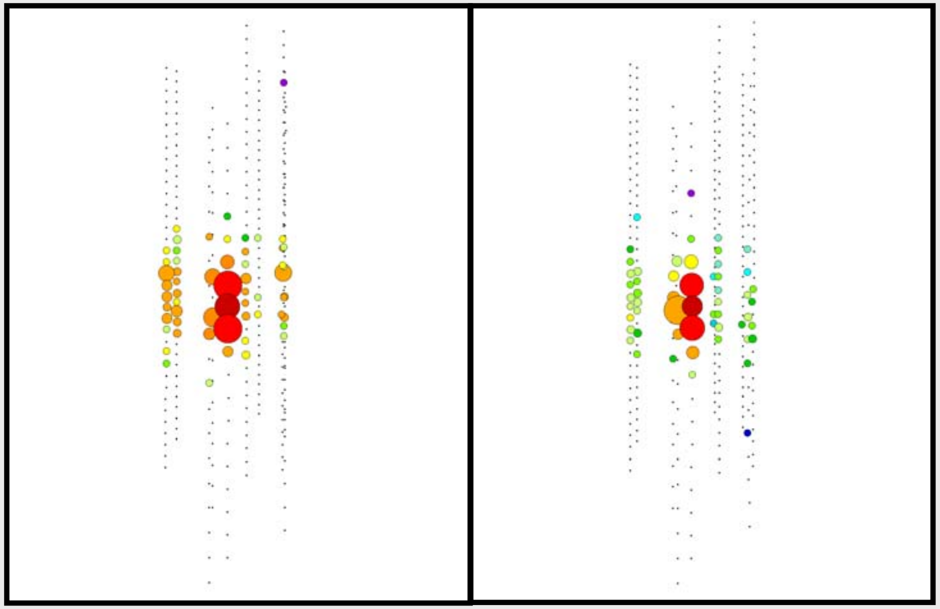


AMANDA Is Working Well

- **Sensitivity to up-going muons demonstrated with CC atm. ν_μ interactions:**



- **Sensitivity to cascades demonstrated with *in-situ* sources (see figs.) & down-going muon brems.**



In-situ light source **Simulated light source**

- **AMANDA also works well with *SPASE:***
  - **Calibrate AMANDA angular response**
  - **Do cosmic ray composition studies.**

AMANDA Results

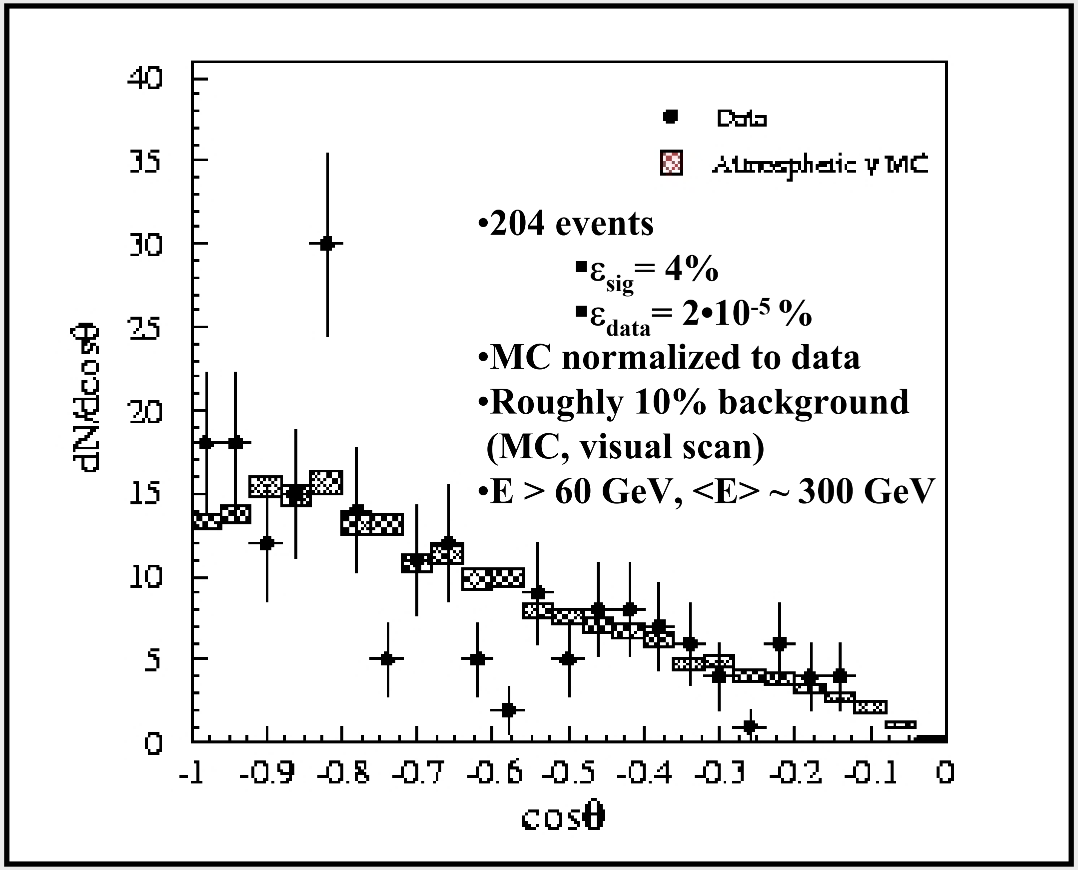
Dataset	Analyses (published; <u>under internal review</u>); All analyses done ****BLIND****
1997	Atmospheric neutrinos; searches for WIMPs, supernovae, <u>point sources</u>, diffuse sources, EHE ν, <u>UHE cascades</u>, GRBs; cosmic-ray composition, relativistic monopoles
1998	Difficult year for detector. Third reconstruction underway; analysis to follow.
1999	Smoother year. Fully reconstructed; data being analyzed. See 1997 for topics.
2000	~3x bigger → >3x better. *Preliminary* results on atmospheric neutrinos, searches for point sources, diffuse sources, cascades, GRBs.
2001	Analyses in progress.
2002	Collecting data. Online filtering in place at Pole.

Reconstruction Handles

	up/down	energy	source direction	arrival time
Atmospheric ν_μ	x			
Diffuse ν, EHE events	x	x		
Point Sources: AGN,WIMPs	x	x	x	
GRBs	x	x	x	x

“Something Old”: 1997 Data
1. Atmospheric ν’s, Our Test Beam

The only known high energy ν source is also the hardest to work with: low E with no temporal or directional handle.



Astro-ph/0205109, submitted to PRD

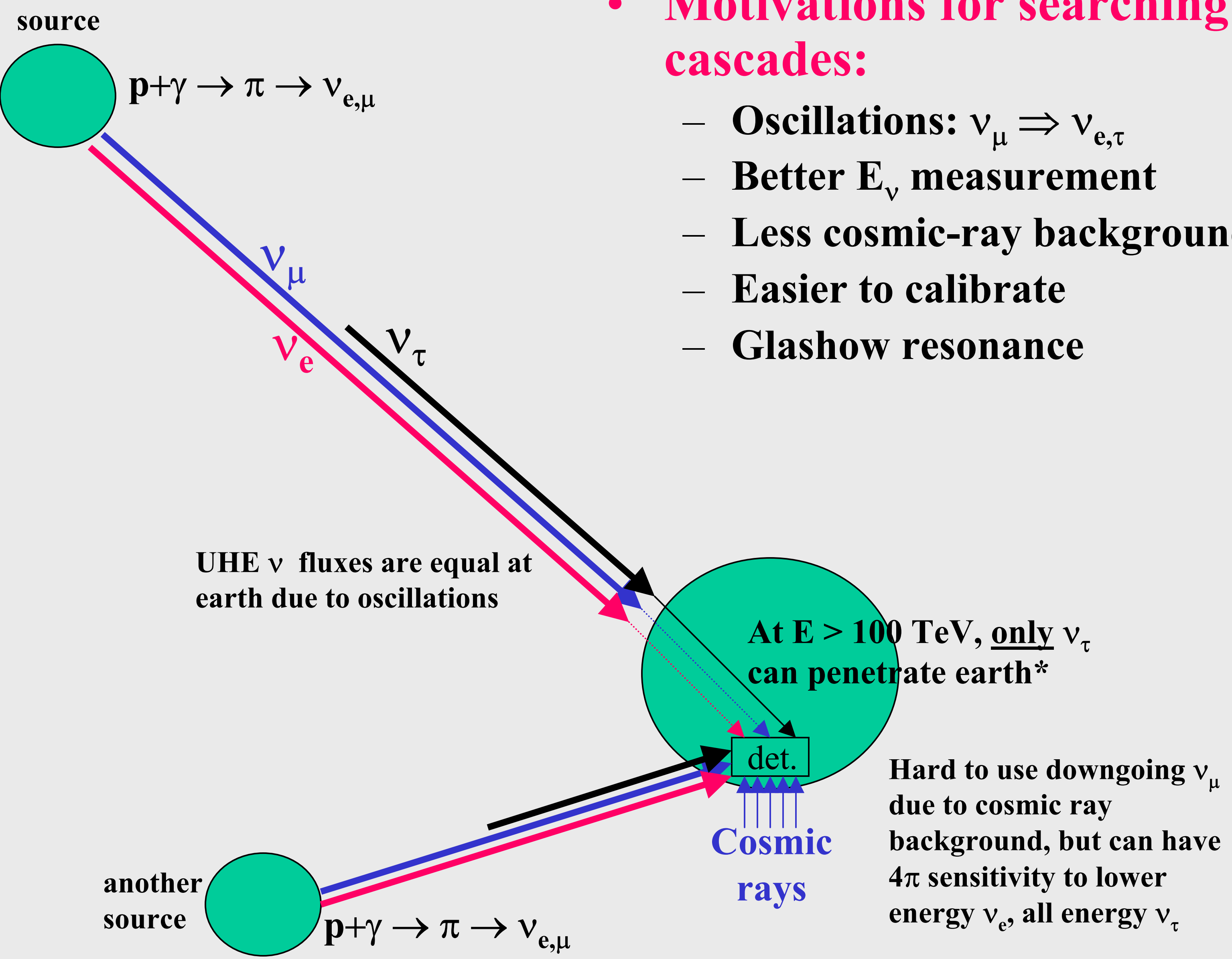
	MC down μ	MC atm ν	Data
Triggers	8.8e8	8,978	1.0e9
Upgoing	1,848	557	4,935
q > 7	17 ± 5	279 ± 3	204

204 needles in a really big haystack

EASIER WITH AMANDA-II!

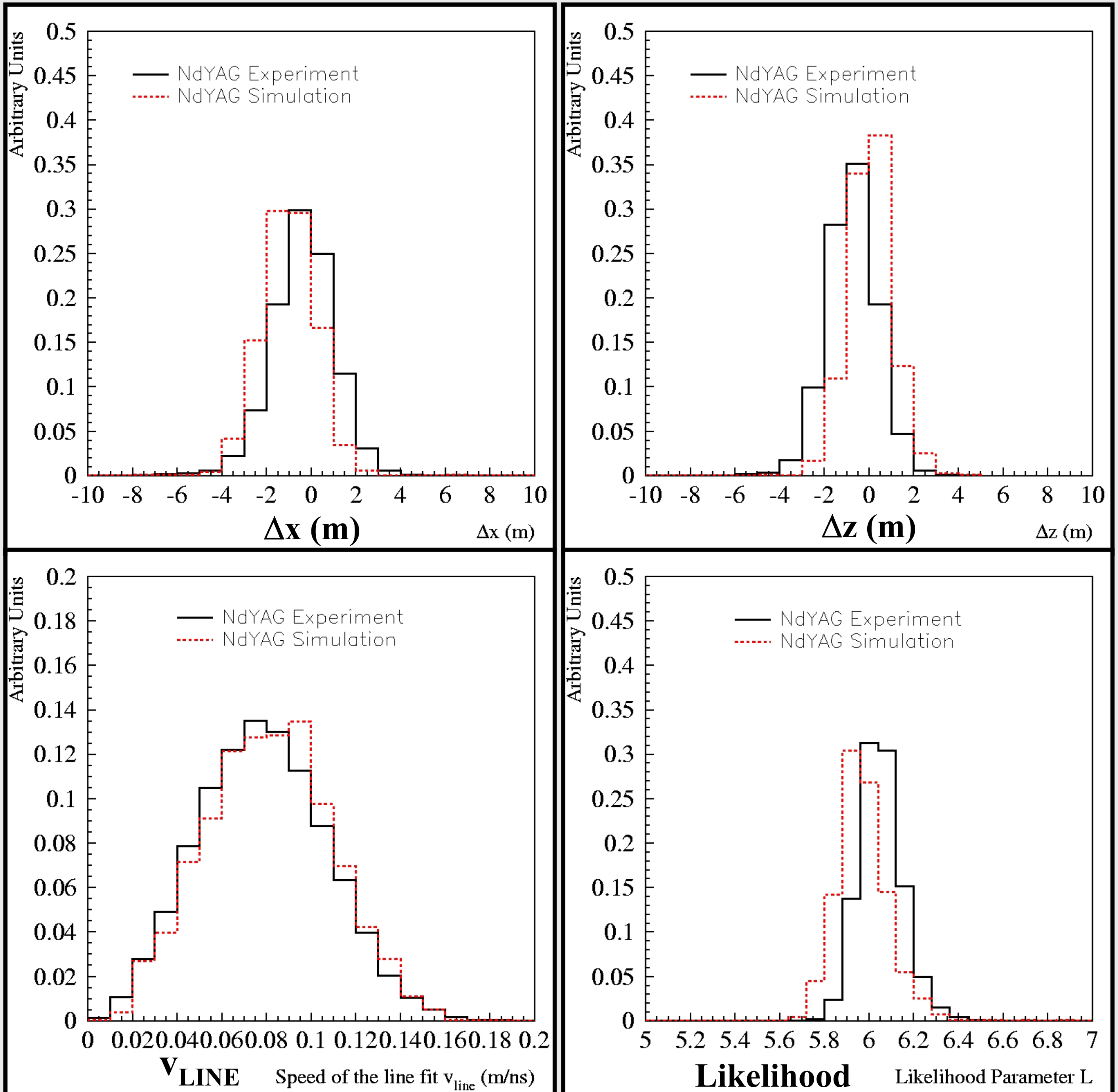
2. EM & Hadronic Showers: "Cascades"

- **Motivations for searching for cascades:**
  - Oscillations: $\nu_\mu \Rightarrow \nu_{e,\tau}$
  - Better E_ν measurement
  - Less cosmic-ray background
  - Easier to calibrate
  - Glashow resonance



*Halzen & Saltzberg

Response to Cascades: Simulated vs. Actual In-Ice Laser Data



<u>Good agreement!</u>

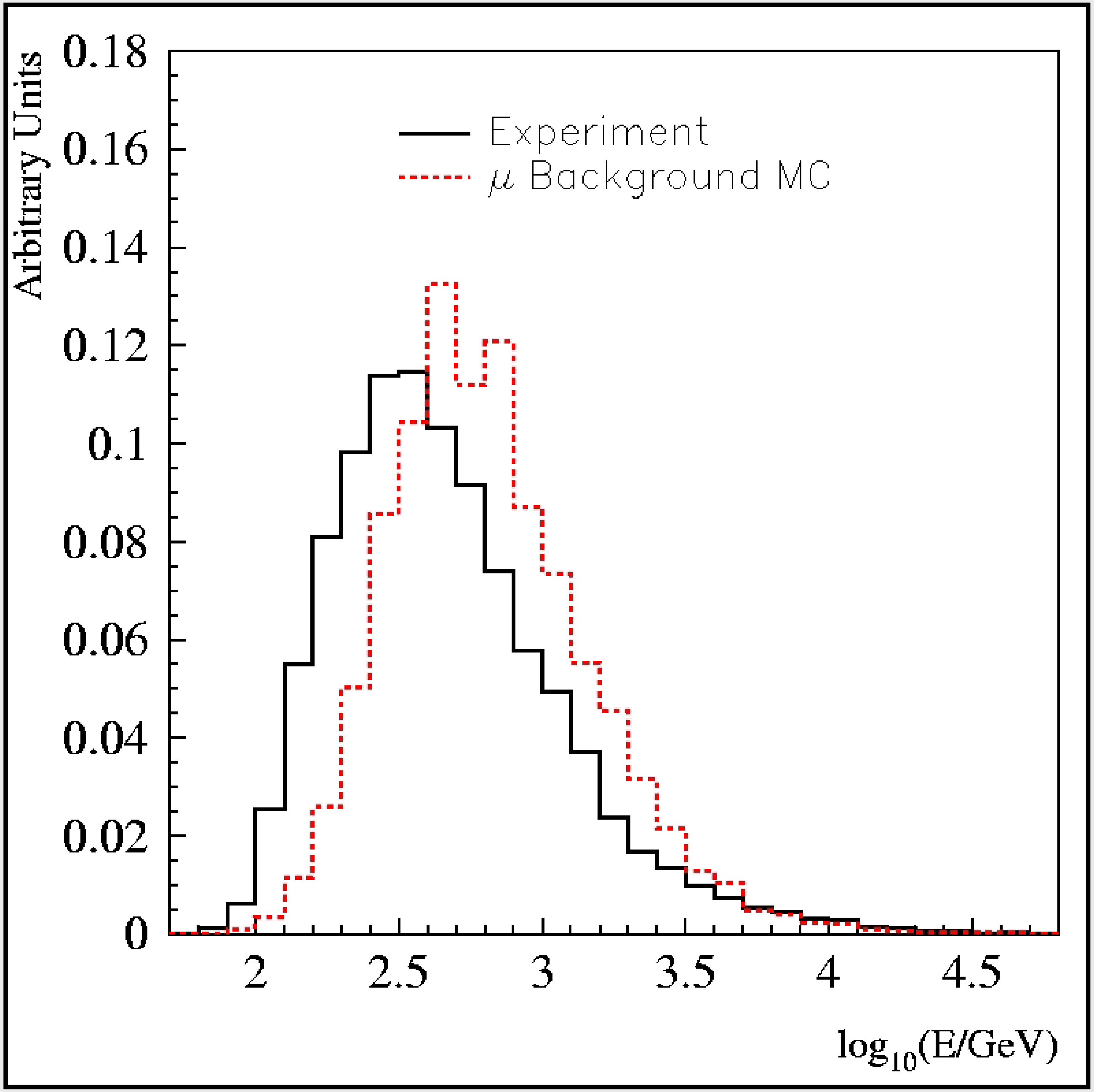
Disagreements: Understood in light of known systematic uncertainties.

Response to Cascades: Cosmic Ray Muon Brems, Simulated vs. Measured

Discrepancy due to uncertainties in:

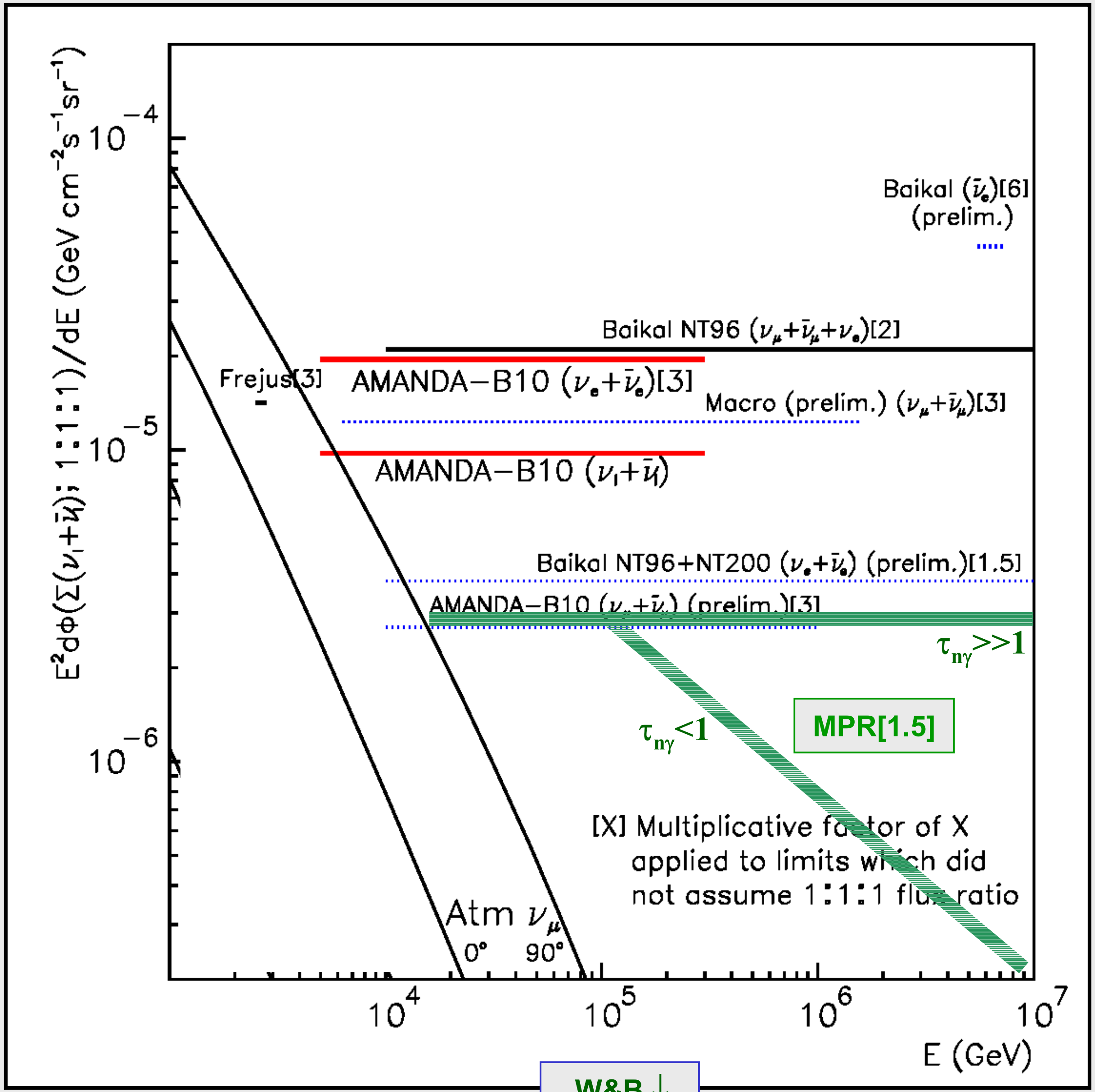
- **ice optical properties**
- **OM sensitivity**
- **cosmic-ray spectrum**
- **rate of μ energy losses**

Agreement restored by shifting energy scale by 0.2 in $\log_{10}E$. Taken into account as systematic.



New Result, 1997 Data: Cascade Search

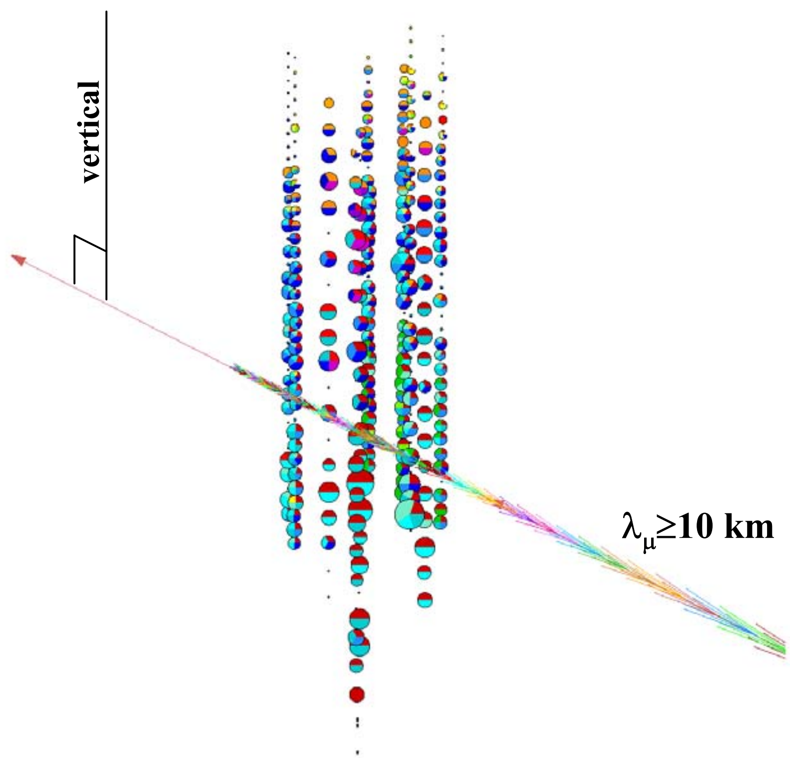
- **Unique result:**
  - Limit on ***all*** ν flavors and
  - Uses ***full*** reconstruction of cascade
- **Analysis gets easier and more competitive with muons as detector grows in size, especially at higher energies**



W&B ↓

3. EHE ($E \geq 10^{15}$ eV) Event Search

EHE events very bright; many PMTs detect multiple photons

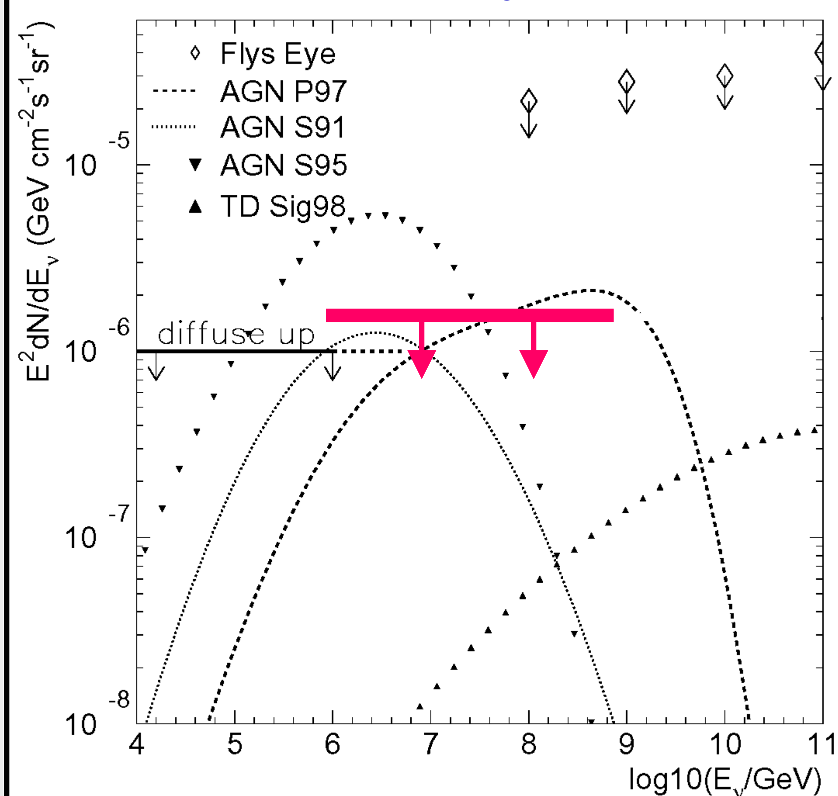


Note: At EHE energies, expect only ~horizontal events*

*Klein & Mann, 1999

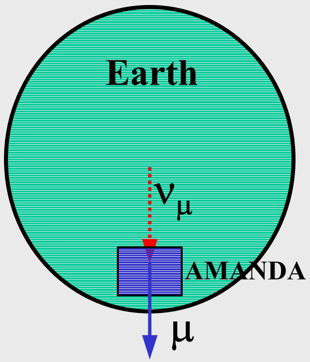
- **Main background: muon "bundles"**
  - Comparable N_{PMT} but smaller N_γ
- **Calibrate with *in-situ* N_2 laser**
- **Still evaluating systematic uncertainties**
- **See poster I-1 by S. Hundertmark**

Preliminary Limit

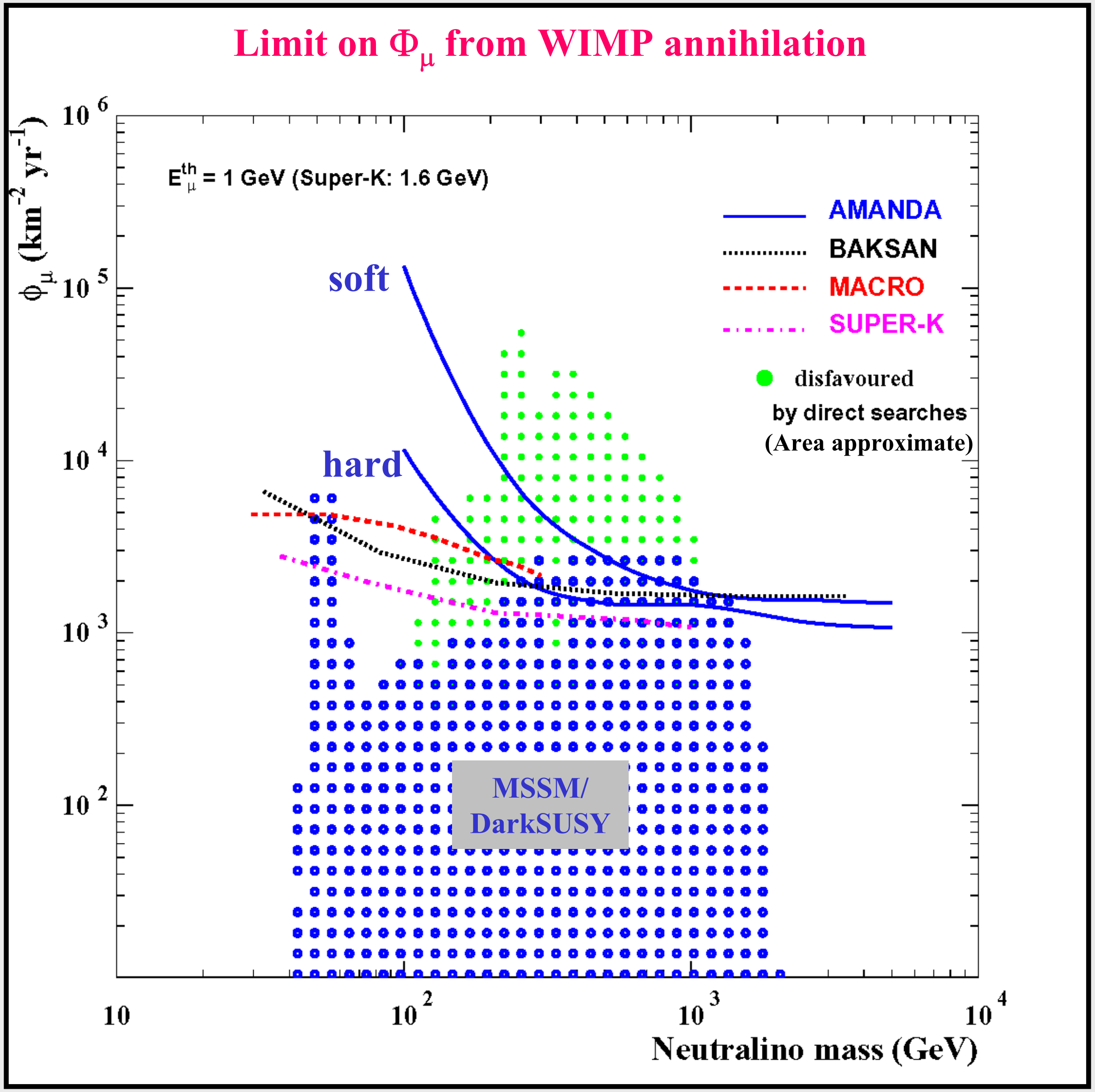


4. WIMP Search

WIMP annihilation at Earth's center, use directional handle:



cf: Lars Bergstrom's talk

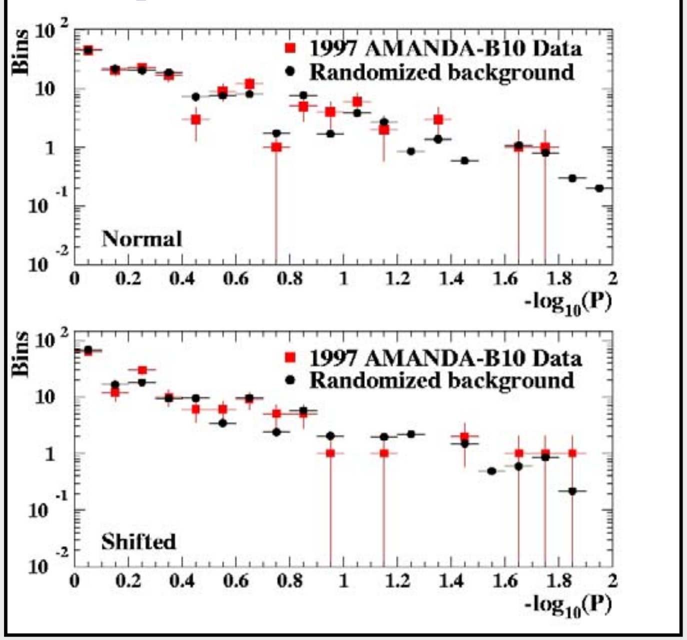


astro-ph/0202370, submitted to PRD

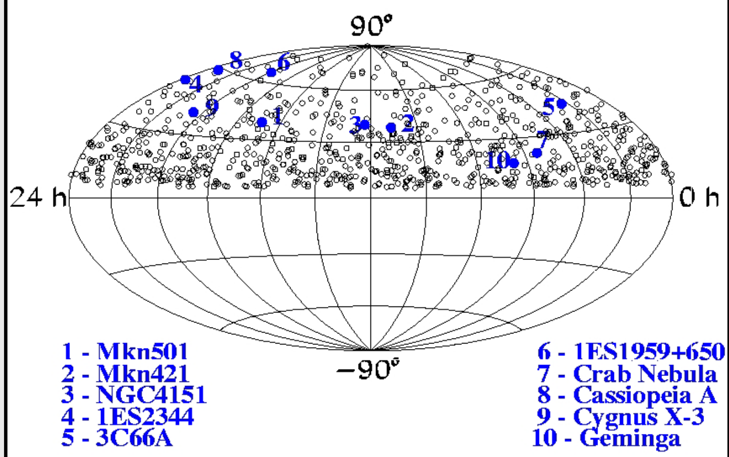
5. Point Source Search

Point Sources: In each 12°x12° angular bin, look for more up-going μ's than expected from statistical fluctuations of a random distribution

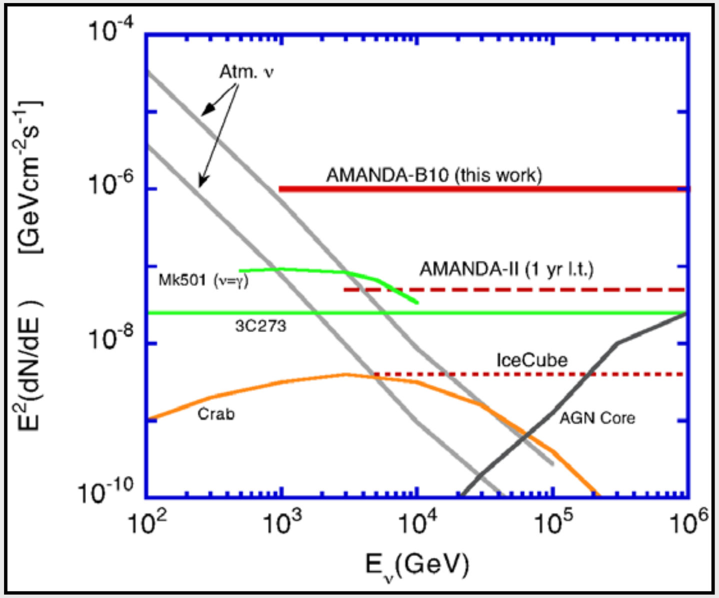
Comparison to random distribution



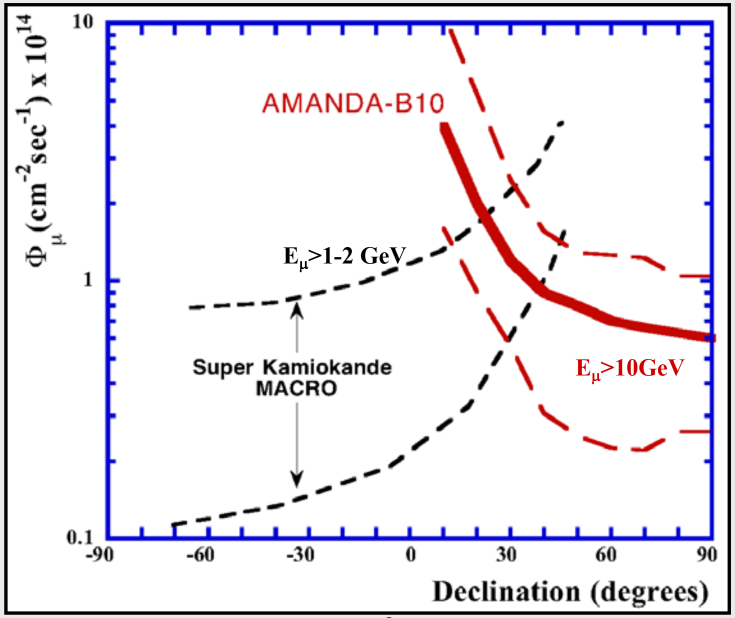
Sky plot



Results:



Muon flux limit (E^{-2} spectrum assumed)

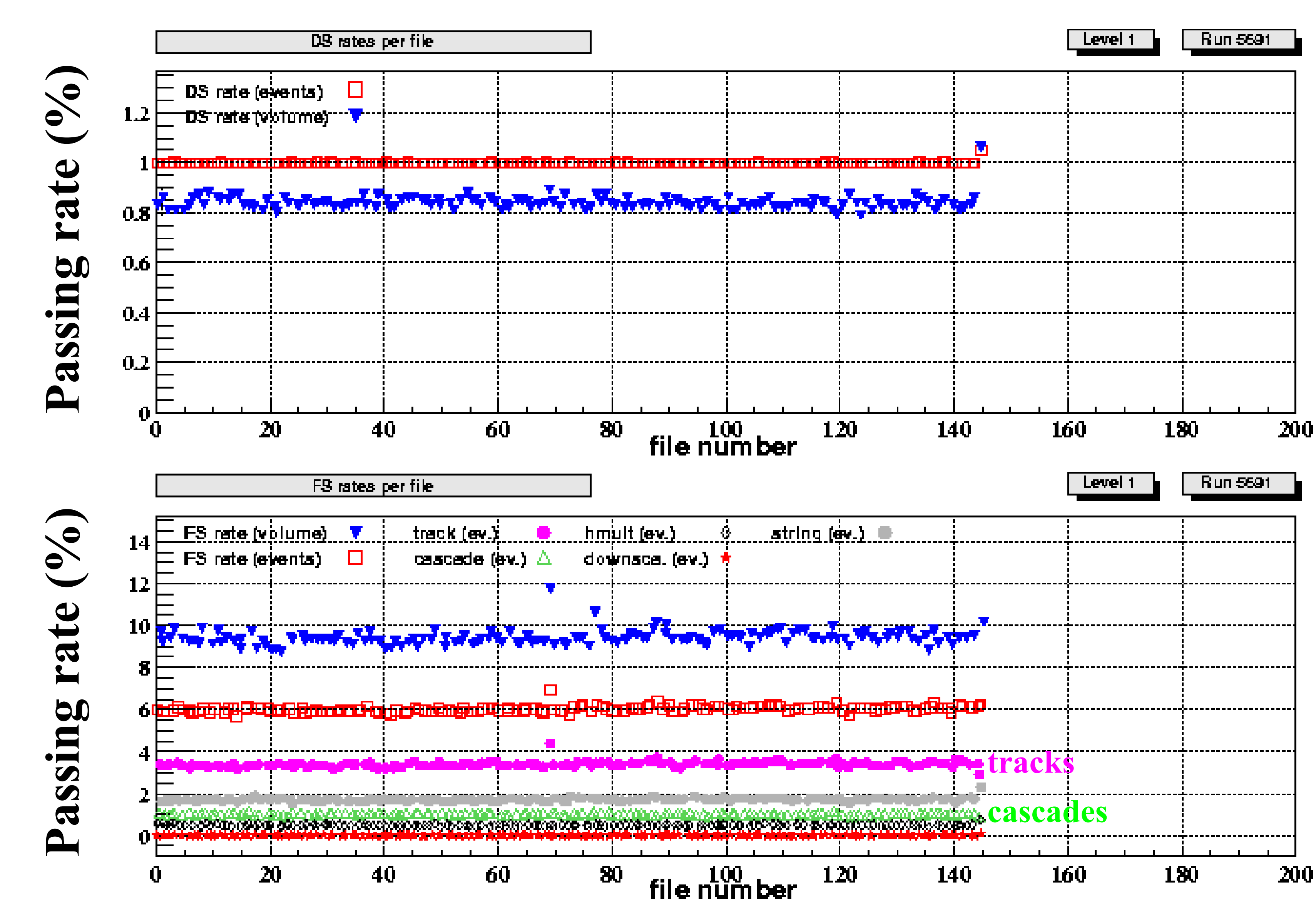


Neutrino flux limit (E^{-2} spectrum assumed)

“Something New”: Preliminary Results from AMANDA-II

- **A-II is much larger than AMANDA-B10**
  - Higher expected event rates
  - Improved angular acceptance near horizon
  - More efficient reconstruction of muons and cascades
    - As of 2002, initial reconstruction is done in real time
- **Preliminary results:**
  - Atmospheric neutrinos
    - the “test beam” for muons
    - anticipate ~5 clean ν/day with very simple set of selection criteria
  - Diffuse cascade search
  - Diffuse ν_μ source search
  - Point source search
  - GRB search

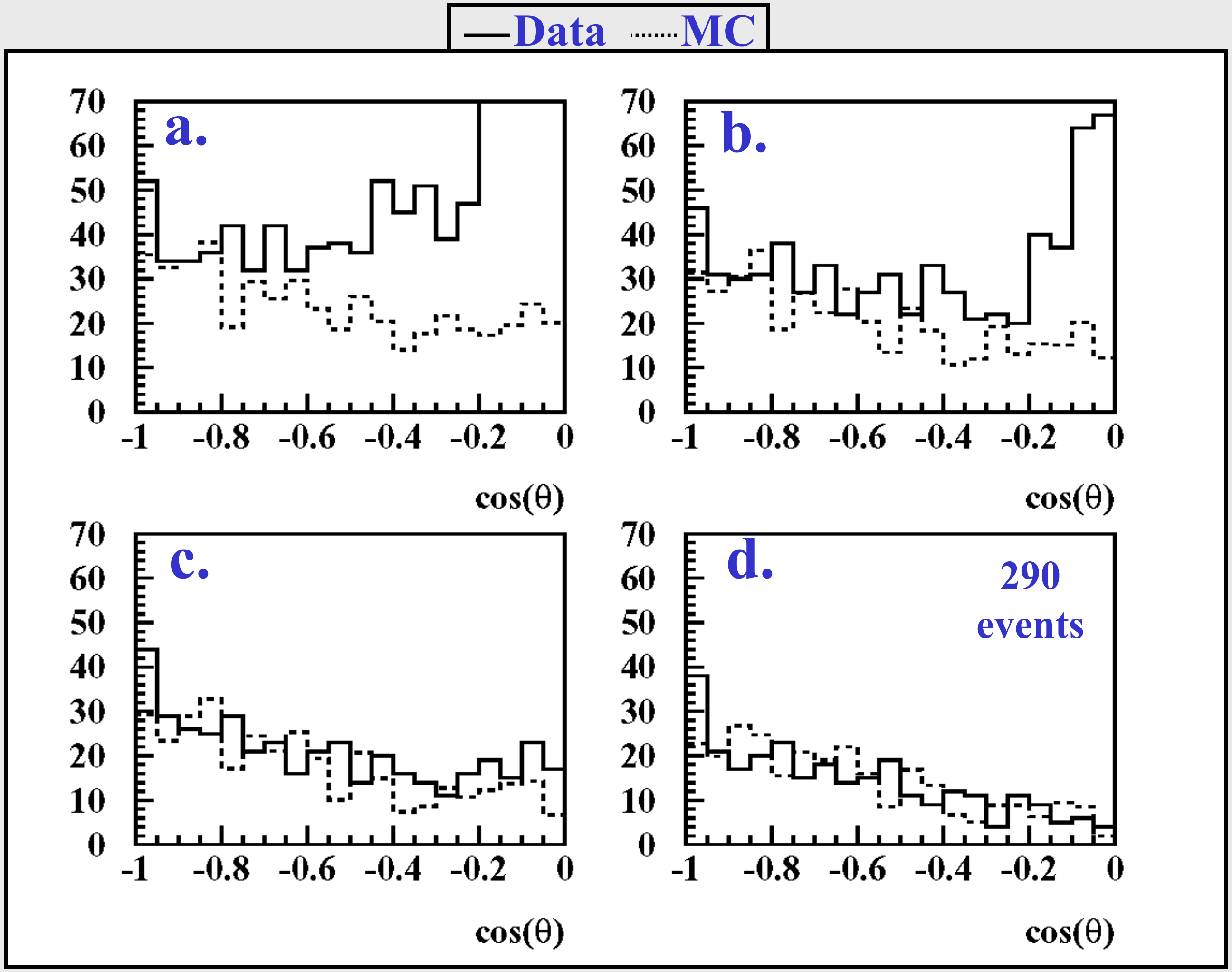
2002 Data: Real Time Analysis



Weds. 15 May, 2002

"Something New": 2000 Data
1. Atmospheric ν's, Still Our Test Beam

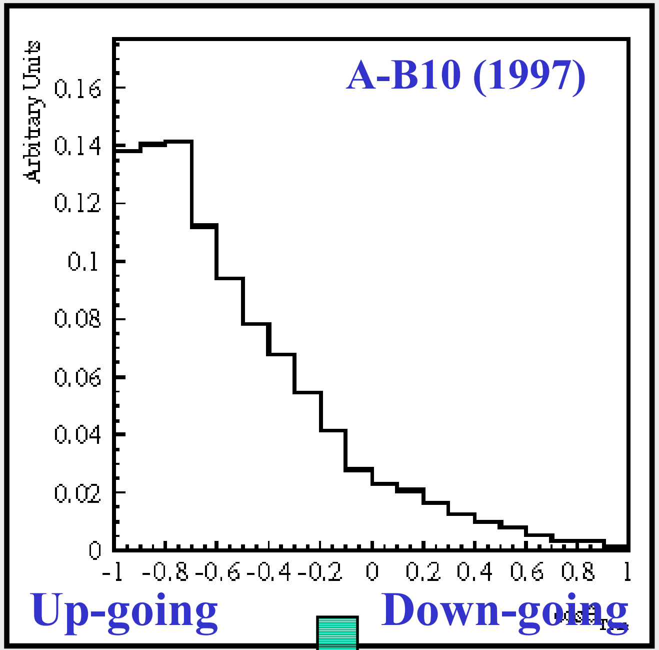
- **Selection Criteria:**
  - $N_{hit} < 50$
  - Zenith > 110°
  - High fit quality
  - Uniform light deposition along track
- **Excellent shape agreement!**
  - Less work to obtain than with A-B10!

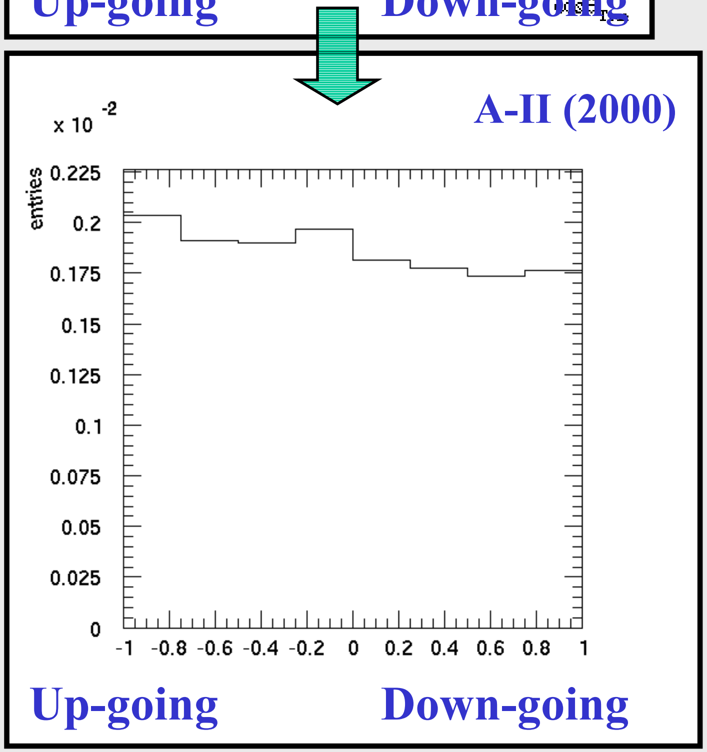


Gradual tightening of cuts extracts atm. ν signal
Notes: far from optimized; uses 60% of data; expect ~500-1000 atm. ν events eventually.

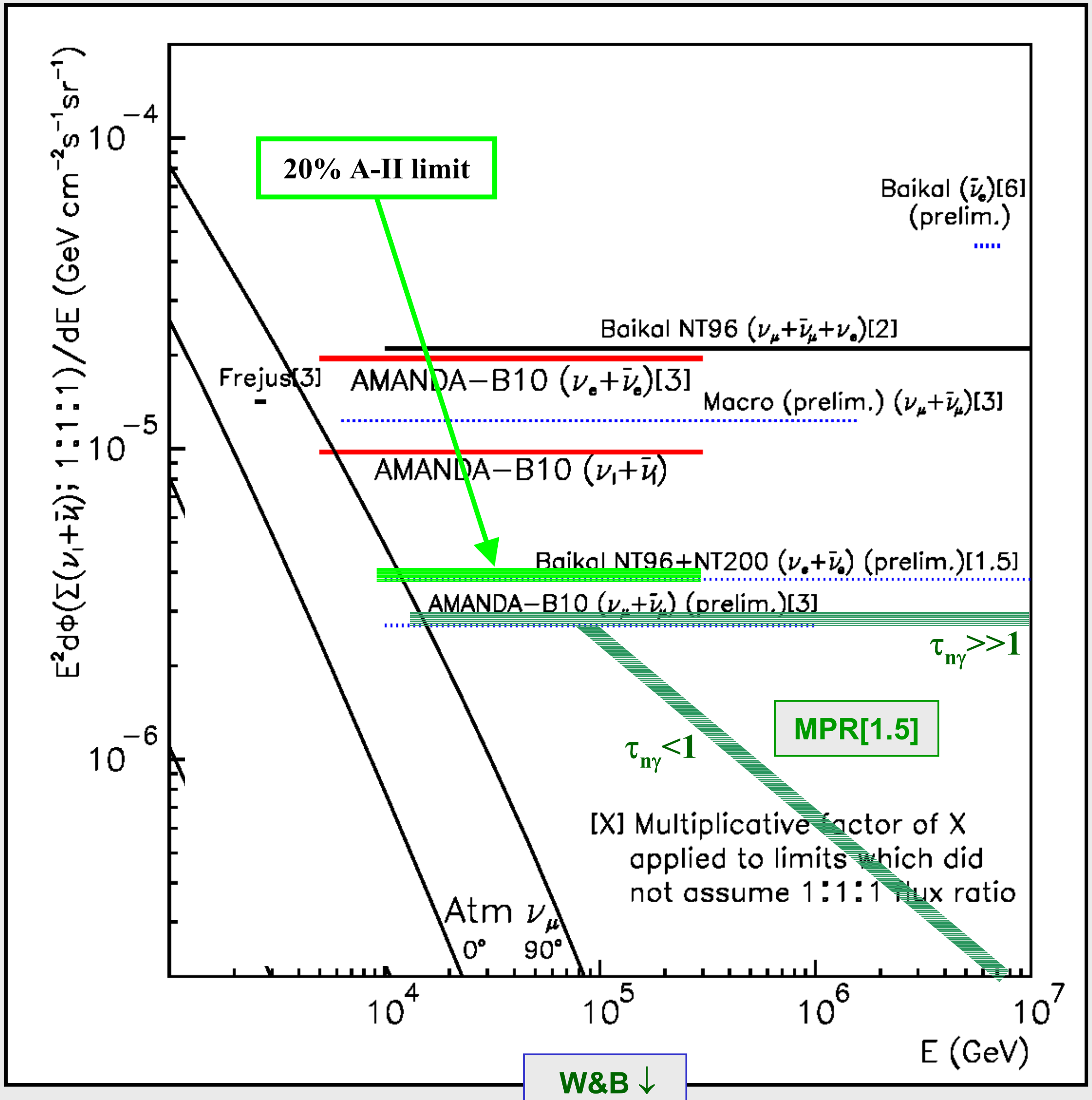
2. Cascade Search

- **Larger detector size**
  - Improves angular acceptance to $4\pi \rightarrow$
  - Easier to reject backgrounds
  - Increases reach in energy by 3x to ~1PeV
  - Will enable us to push limit down by about an order of magnitude—or to *see something!*
- **Current analysis based on 20% subsample of the 2000 data in accordance with our blind analysis procedures**
  - At current AMANDA limit of $\Phi \leq 10^{-6}$ GeV cm^{-2} s^{-1} (muon analysis), expect about one signal event in 20% sub-sample
- **See poster I-2 by M. Kowalski**





Preliminary Cascade Limit (20% of 2000 Data)

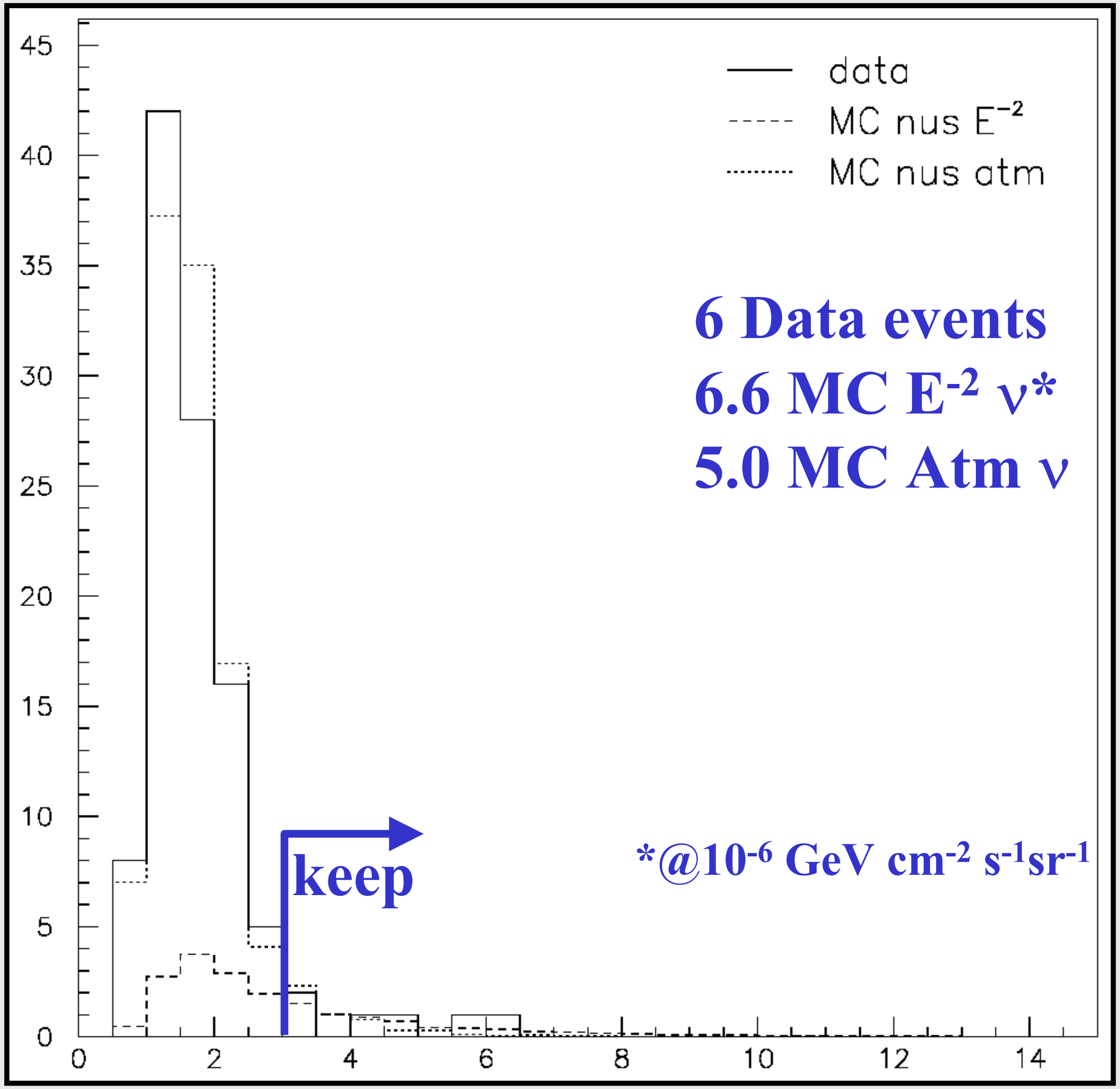


Expected signal

Astrophysical ν's	*Predicted* events in 100% of 2000 data
$\Phi_{\nu_e+\nu_e} = 10^{-6} E^{-2}$ GeV cm^{-2} s^{-1}	5.5
$\Phi_{\nu_\tau+\nu_\tau} = 10^{-6} E^{-2}$ GeV cm^{-2} s^{-1}	3.2
Atmospheric ν's	***Predicted* events in 100% of 2000 data**
ν_e (CC), $\nu_e+\nu_\mu$ (NC)	0.15
Prompt charm (RQPM)	0.50

3. Diffuse ν_μ Search

- **Analysis:**
  - Look for good muon tracks with channel density $\rho_{ch} > 3$
  - Normalize background to $N_{hit} < 50$ data
- **Preliminary results using 20% of 2000 data**
  - No systematics incorporated!
  - Sensitivity*: $\sim 8\times10^{-7}$
  - <u>*Preliminary*</u> Limit:
    - $\leq \sim 10^{-6}$ GeV $cm^{-2}s^{-1}sr^{-1}$
    - ~same as *full* 1997



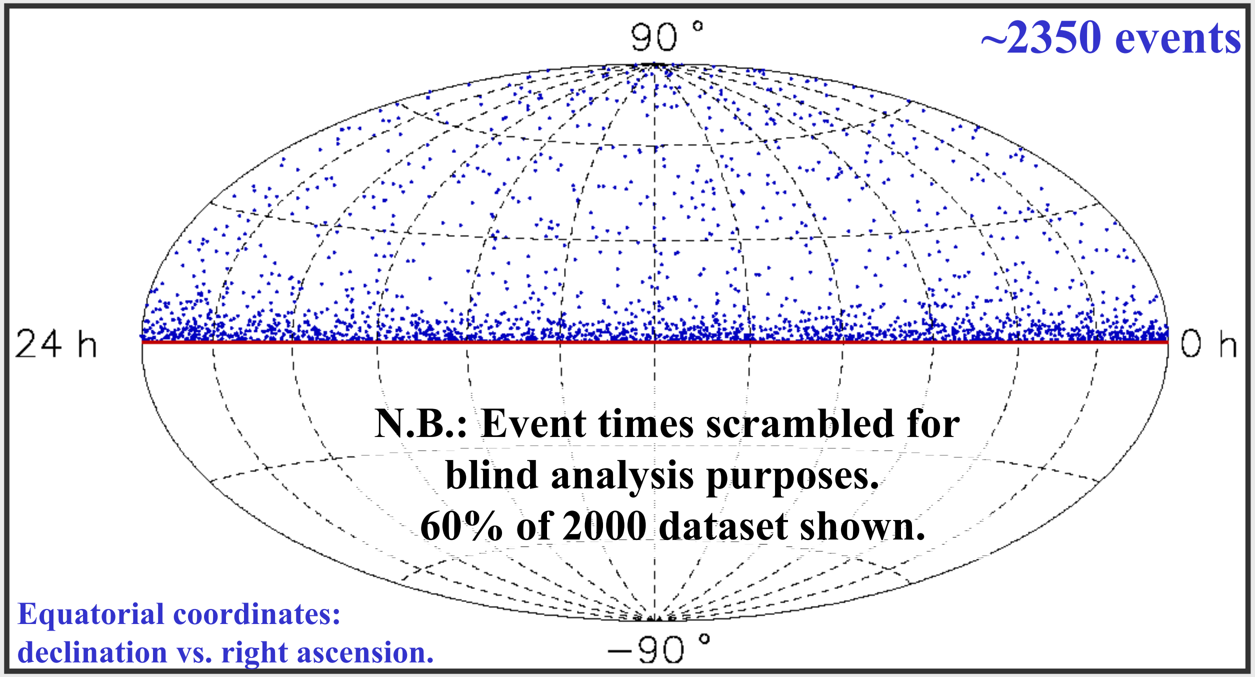
Hit channels/10m tracklength

*Average limit from ensemble of experiments w/no signal

4. ν_μ Point Source Search

- Improved coverage near horizon
- In $6^o \times 6^o$ bin, for E^{-2} spectrum, $10^{-8} cm^{-2} s^{-1}$ flux:
  - ~2 signal events
  - ~1 background event
- Sensitivities calculated using background levels predicted from off-source data

Sky plot (Preliminary)



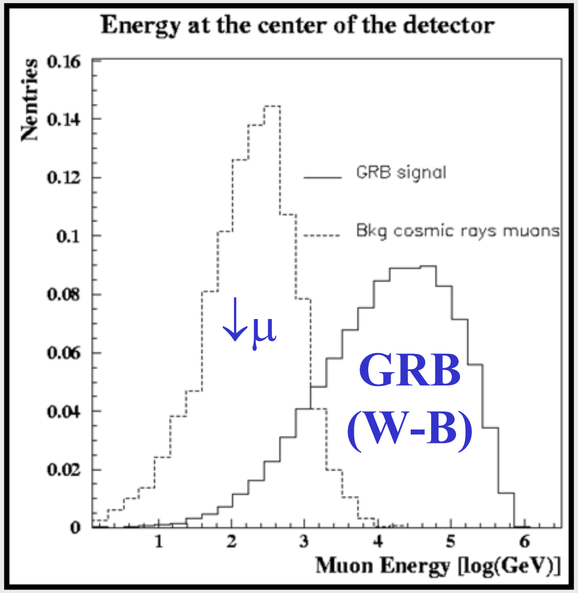
Sensitivities (Preliminary)

Source\Sensitivity	muon ($\times 10^{-15} cm^{-2} s^{-1}$)	ν($\times 10^{-8} cm^{-2} s^{-1}$)
Markarian 421	2.6	1.1
Markarian 501	2.5	1.0
Crab	4.0	1.3
Cass. A	2.1	1.0
SS433	11.0	2.4
Cyg. X-3	2.6	1.1

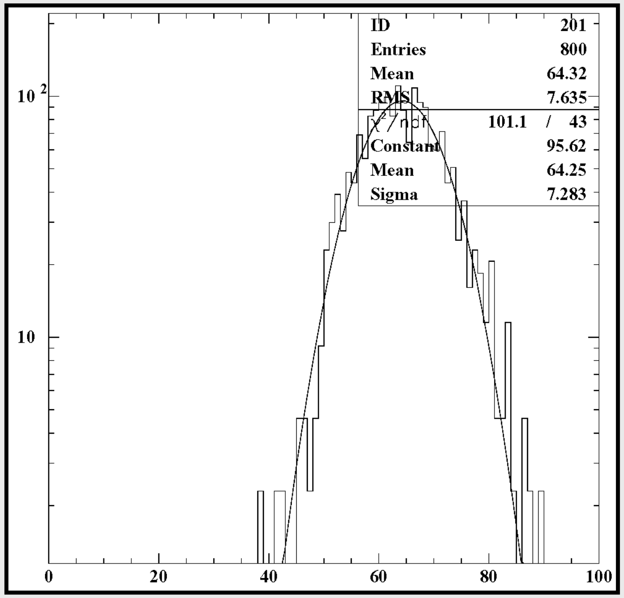
PRELIMINARY

5. GRB ν_μ Search

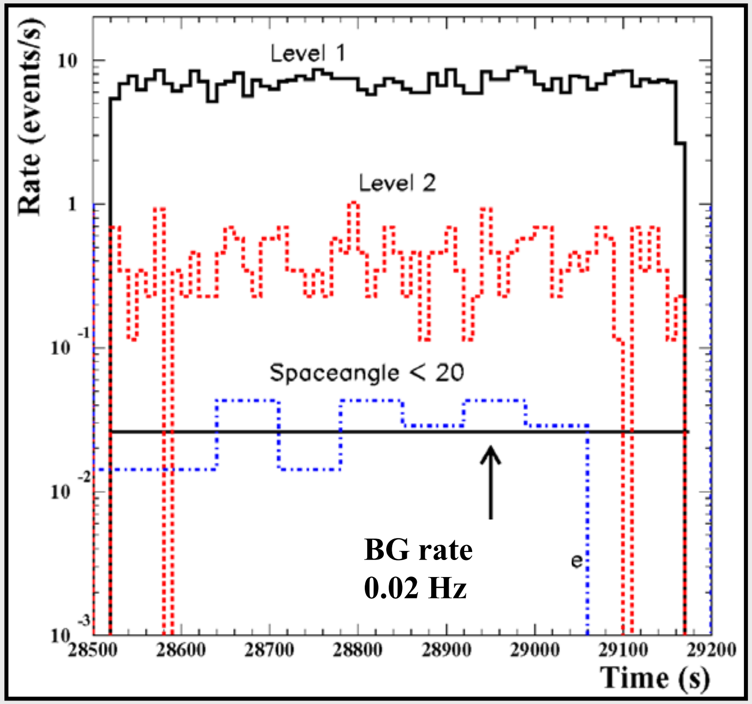
- Look for ν_μ's in 10-100 TeV range, coincident with a GRB
  - Use off-source & off-time data—ideal for maintaining blindness
- 2000 data very stable
- Virtually background-free analysis
  - only need BG rejection factor of 10^{-3}–10^{-4} (orders of magnitude less demanding than other analyses)
- Anticipate having ~500 GRBs to look at with 1997—2000 datasets
- Waxman-Bahcall limit still out of reach, but we're getting there!



E_μ

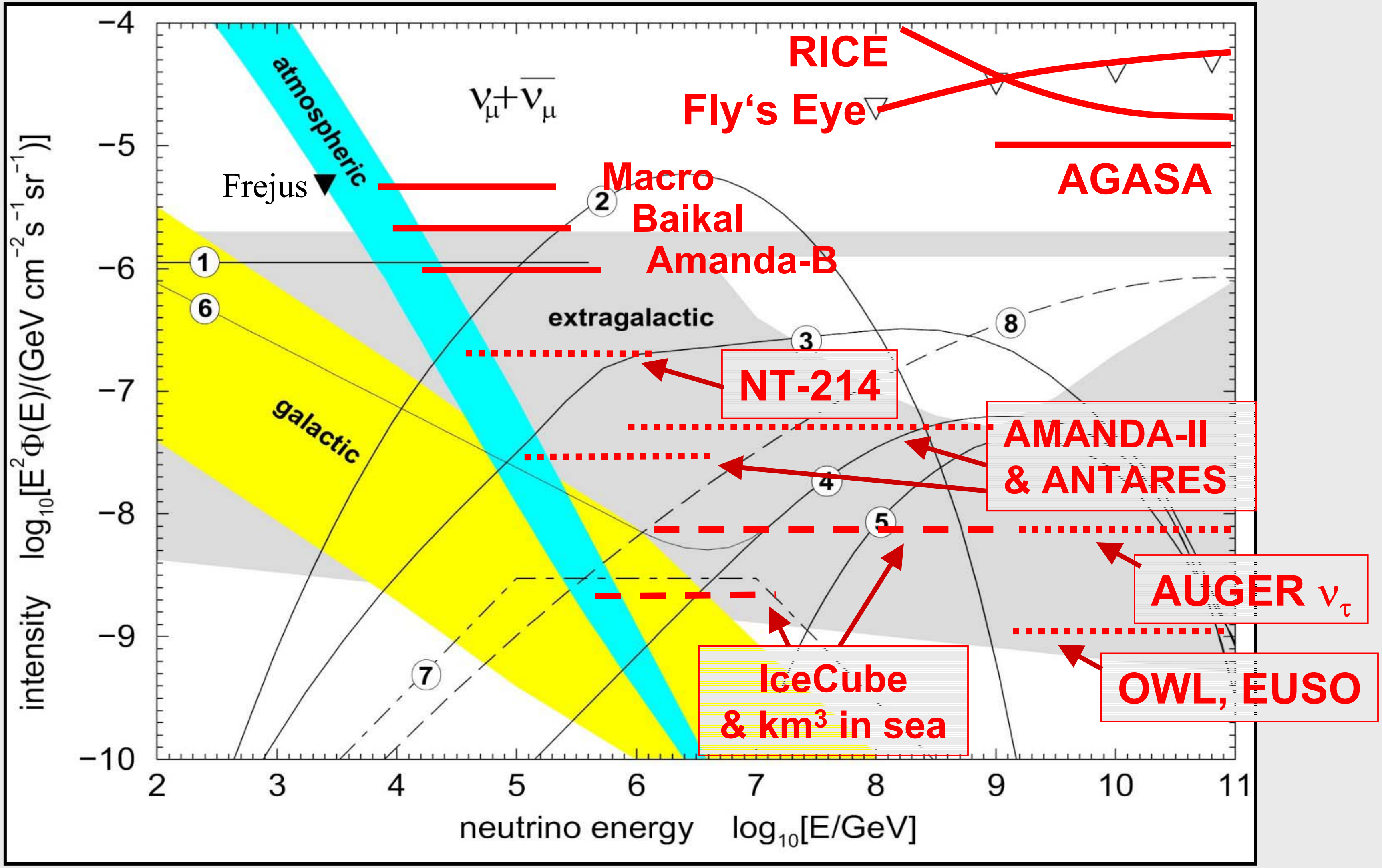


Average event count/10s (some cuts applied)



Gradual cut tightening in a time window around a particular GRB (10^{-3}–10^{-4} bkgd. rejection attainable).

Grand Summary

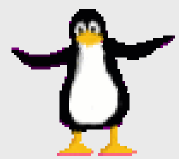


Courtesy: Learned & Mannheim; Spiering

Conclusions

- **AMANDA-B10**
  - **Continues to produce results, many of which are competitive or better than existing measurements, & challenge existing models**
  - **Additional B10 data from 98 & 99 is being analyzed**
- **AMANDA-II**
  - **As expected, detector works much better than B10 alone**
    - **Larger instrumented volume**
    - **More mature experiment**
  - **Preliminary results based on 20% sub-samples of 2000 data are already comparable to B10 results from *full* 1997 dataset**
  - **2001, 2002 data ready to be processed and analyzed**
  - **Detector upgrade: Adding full pulse digitization capability to extend physics reach**
  - **Will integrate A-II into…**
- ***IceCube: The Second Honeymoon* (see talk by A. Karle)**

THE END



I lied, but only about the penguin.

AMANDA/IceCube postdoc positions available! Contact me afterwards or email me at cowen@phys.psu.edu